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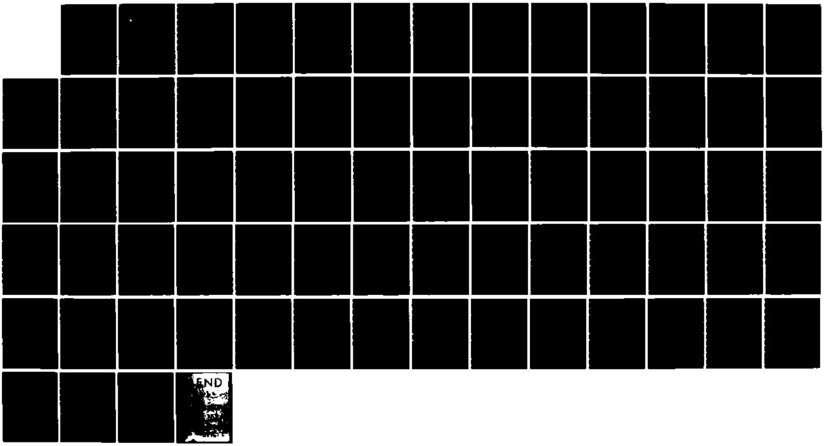

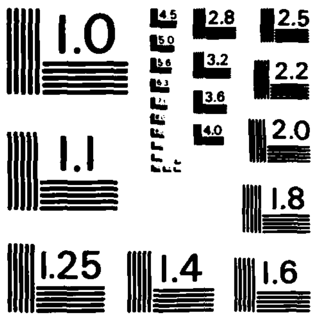

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CR 85.005

NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

PROCEDURES FOR LONG-TERM EVALUATION OF HEAT RECOVERY INCINERATOR SYSTEMS

October 1984

An investigation conducted by:
VSE Corporation
1200 Paseo Camarillo
Camarillo, CA 93010-6093

N00123-82-D-0149

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METRIC CONVERSION FACTORS

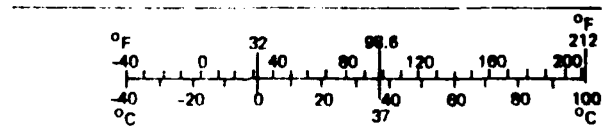
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: CR 85.005 / 2. GOVT ACCESSION NO.: A147723	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Procedures for Long-Term Evaluation of Heat Recovery Incinerator Systems	5. TYPE OF REPORT & PERIOD COVERED: Final Feb 1984 - Oct 1984
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Dennis Leipert, USE	8. CONTRACT OR GRANT NUMBER(s): N00123-82-D-0149
9. PERFORMING ORGANIZATION NAME AND ADDRESS: VSE Corporation, 1200 Paseo Camarillo, Camarillo, CA 93010-6093	10. PROGRAM ELEMENT PROJECT, TASK AREA & WORK UNIT NUMBERS: Y0817-004-01-213
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Civil Engineering Laboratory, Port Hueneme, CA 93043	12. REPORT DATE: October 1984
	13. NUMBER OF PAGES: 90
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Naval Facilities Engineering Command, 200 Stovall Street, Alexandria, VA 22332	15. SECURITY CLASS (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

HRI, RAM, solid waste, energy recovery

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A number of HRI facilities are not operating as designed. Part of the problem has been a lack of proper data collection and analysis procedures. The set of procedures developed by this report are intended to correct this problem. Procedures are detailed in the areas of data collection and data analysis for existing facilities to identify inadequate

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equipment performance and for use in the design of future HRIs. The information obtained can be used to increase or modify maintenance and replacement schedules or to justify design changes.

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FIGURES

1.0 INTRODUCTION

1.1 Background

The Resource, Conservation, and Recovery Act (RCRA) of 1975 mandates the use of fuel derived from recovered waste material to the maximum extent practicable in federally owned fossil fuel-fired energy systems. In this regard, the Naval Civil Engineering Laboratory (NCEL) at Port Hueneme, CA, has been directed by the Department of the Navy to undertake a research and development program for Heat Recovery Incinerator (HRI) systems. Two HRI installations have been developed and studied by the Navy; one located at NAS Jacksonville and the other at NS Mayport. This program included the development of evaluation procedures for HRI systems. An assessment of these evaluation procedures was performed. The results of this assessment are presented in this document and provide procedures to determine the reliability, availability, maintainability, thermal efficiency, and cost effectivness for any HRI system.

1.2 Purpose

The purpose of this document is to provide the HRI facility, from the data collector/recorder to the analyst, with the guidance necessary to compute the aforementioned parameters. It specifies in detail the data to be collected, forms to be used, and methods of data analysis including computation of parameters. These parameters have been selected to indicate the salient performance characteristics of the HRI system.

2.0 METHODS OF ANALYSIS

The evaluation procedures comprise the use of a standard set of criteria, definitions, and evaluation techniques that provide for a systematic method of data collection, analysis, and interpretation that can be applied to the performance characteristics of the HRI system. These procedures are aimed at generating parameters that indicate reliability, availability, maintainability (RAM), thermal efficiency, cost effectiveness, and landfill reduction.

2.1 RAM Analysis

RAM analysis incorporates the concepts of reliability, availability, and maintainability to quantify, measure, and analyze the operation and maintenance characteristics of the HRI system.

2.1.1 Reliability

Reliability (R) is the probability that an initially operable item will continue performing its specified function without failure under given conditions for a specified period of time.

Reliability is generally expressed as a probability value (percent chance), but is frequently indicated by the term Mean Time Between Failures (MTBF). MTBF expresses the average amount of equipment operating time that goes by before an equipment breakdown will occur. See Section 7.1 for application of reliability concepts.

2.1.2 Availability

Operational availability (A_o) is the probability that an item will be capable of performing its specified function when called upon to do so at any random point in time.

Operational availability is generally expressed as a probability value (percent chance) and is derived by combining reliability and maintainability concepts. The process of computing availability compares the time of successful equipment operation (high reliability equates to extended equipment operating time) to downtime due to equipment maintenance (high maintainability equates to a low amount of maintenance time). See Section 7.2 for application of availability concepts.

2.1.3 Maintainability

Maintainability (M) is the probability that after maintenance is initiated under given conditions, the capability of an item to perform its specified function will be retained or restored within a specified period of time.

Maintainability is generally expressed as a probability value (percent chance) but is frequently indicated by the term Mean Time To Repair (MTTR). MTTR expresses the average amount of time it takes to repair an equipment breakdown. See Section 7.3 for application of maintainability concepts.

2.2 Long-Term Thermal Efficiency

The thermal efficiency of the HRI system is a measure that indicates how many Btus in the form of steam energy are produced per Btu of energy input in the form of solid waste and various fuels. Determining thermal efficiency involves the application of a detailed and standard method of collecting data related to the consumption of input energy sources and steam generation over the long-term course of evaluation (see Section 9.0).

2.3 Long-Term Cost Effectiveness

The cost effectivness of the HRI system is an indication of the cost of operating the HRI system per unit of steam it produces. The cost effectiveness indicator used for the HRI system is the average cost of steam (ACS). Determining ACS involves the careful monitoring of the cost and consumption of items related to operation and maintenance of the HRI system over the long-term course of evaluation (see Section 11.0).

2.4 Percent Landfill Reduction

The two basic functions of the HRI system are to generate steam from the incineration of solid waste and to reduce the volume of solid waste that would otherwise be dumped as landfill. To measure the capability of the HRI system to reduce landfill volume, the percentage of landfill reduction (PLR) parameter is determined. This involves the application of a detailed and standard method of collecting data related to the input of solid waste to the HRI and the removal of the ash residue remaining from the incineration process (see Section 10.0).

3.0 BENEFITS OF ANALYSIS

The knowledge of performance provided by RAM, thermal efficiency, and cost effectiveness evaluation leads the way for a practical and cost-efficient approach to product improvement. It indicates quantified performance data that can be utilized to significantly increase product quality and reliability. HRI system evaluation can indicate:

(1) How effectively a particular design performs its required function.

(2) Required levels of performance that can be used for further development of equipment and system specifications.

(3) Design problem areas and how design improvements can be made.

The cost of an evaluation program can be minimal when it is compared to the high cost of maintenance for poorly designed and unreliable equipment. The federal government has found that, in some cases, the cost of maintenance for unreliable equipment can exceed 10 times the original cost, and that a well-structured evaluation program can reduce this expense considerably.

4.0 OPERATIONAL SCENARIO

The following scenario of Heat Recovery Incinerator system operation is presented as a typical example to aid in understanding the application of the evaluative principles put forth in this report. The example outline portrays operating characteristics generally common to all HRI systems.

4.1 HRI Function

The HRI system has been developed to fulfill two basic functions:

(1) To generate steam with heat energy derived from the combustion of solid waste materials.

(2) To reduce the volume of solid waste materials by incineration, thus reducing landfill.

4.2 System Operation

For purposes of system evaluation, the typical HRI system is divided into four basic areas of operation:

(1) Solid Waste Receiving and Processing.

(2) Incineration.

(3) Ash Removal.

(4) Steam Generation.

The solid waste receiving and processing area handles the initial input of solid waste materials to the HRI. Solid waste materials are weighed and then delivered to the HRI facility by truck and dumped onto a tipping floor. It is then hand- or machine-sorted to remove bulky or noncombustible items. The front-end skip loader pushes the remaining solid waste to a charging area or a storage pit. The solid waste material is then charged into the incinerator by the front-end loader, or lifted by the overhead crane from the storage pit, weighed, and dropped into the incinerator feed hopper.

Typically, a ram feeder pushes the solid waste materials into the primary furnace of the incinerator, where it is burned.

Waste ash materials resulting from the incineration process are removed from the bottom of the primary chamber by the stoking mechanism located on the bed of the incinerator. Typically, the ash drops into a quench tank for cooling and is then removed by the ash removal conveyor and deposited into a waste bin.

The hot gases liberated by the combustion of the solid waste material are drawn through the secondary furnace and boiler by the draft fan. The gases are ignited in the secondary chamber, sometimes using additional oil and oxygen as required, in order to obtain more heat and vent cleaner exhaust gas into the atmosphere. The hot gases continue on into the boiler where they are used to generate steam from boiler feedwater.

To facilitate understanding of HRI system operation, a flow chart of operational events is presented in Figure 1.

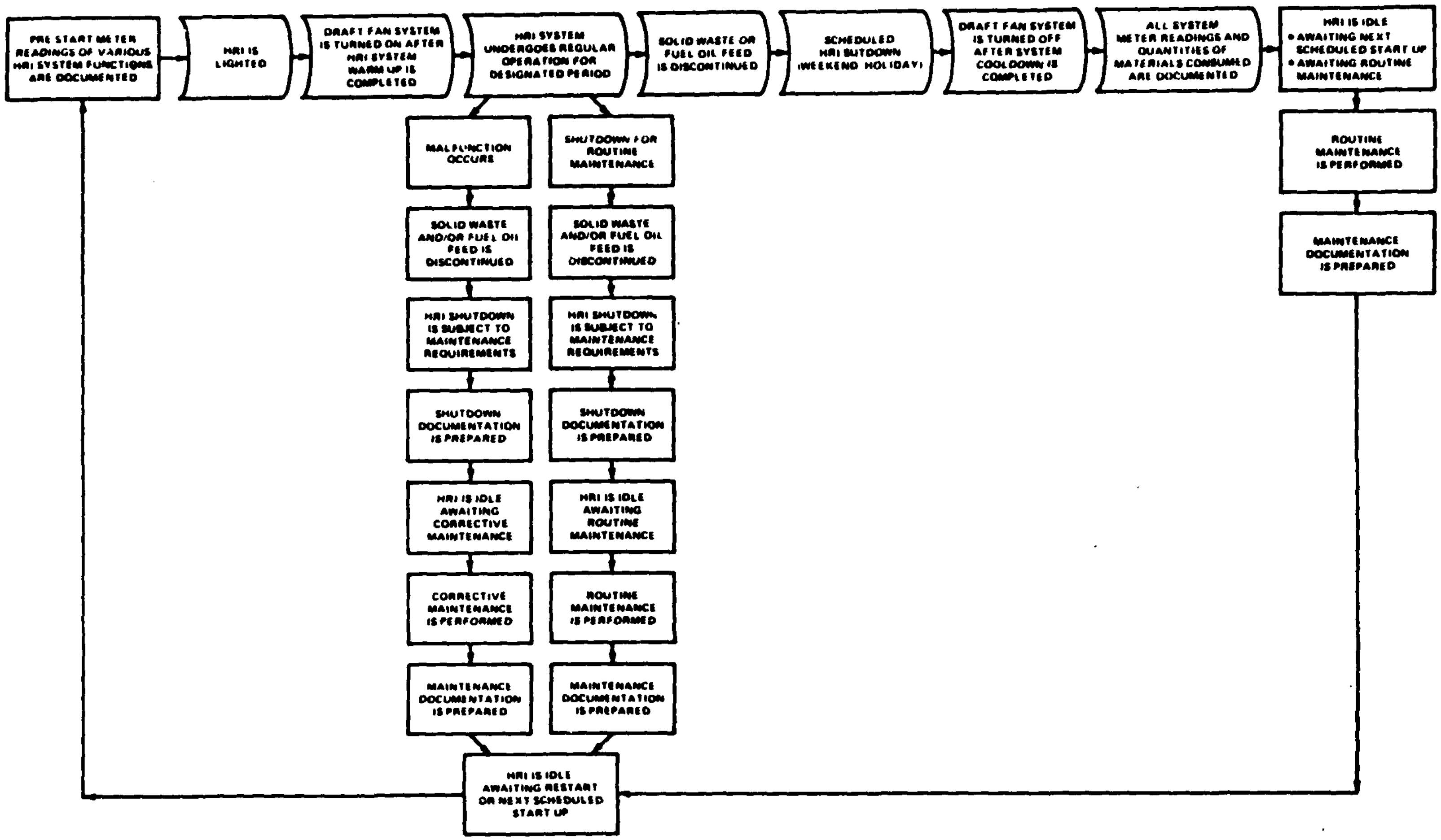

Figure 1. HRI Startup/Shutdown Cycle

5.0 DOCUMENTATION

To conduct an accurate and reliable evaluation of HRI system operation, careful attention must be given to the data collection process. Calculation of RAM, thermal efficiency, and cost-effectiveness parameters requires the input of specific HRI operation and maintenance data. It is important that standard forms of documentation be used to ensure the complete and consistent recording of these data. Collection and treatment of the required input data are discussed further in Appendix A.

There are six required forms of documentation used to collect HRI operation and maintenance data:

(1) FORM 1 - STARTUP/RESTART

(2) FORM 2 - SHUTDOWN

(3) FORM 3 - CORRECTIVE MAINTENANCE

(4) FORM 4 - ROUTINE MAINTENANCE

(5) FORM 5 - WEEKLY DATA TOTALS

(6) MAINTENANCE EVENT SUMMARY TABLE

Forms 1 through 5, along with instructions for their use, are presented in Appendix B. The Maintenance Event Summary Table with instructions is presented in Appendix C.

6.0 DATA COLLECTION

The data required to develop RAM, thermal efficiency, and cost effectiveness parameters are divided into six categories:

(1) Operational and maintenance time categories and man-hour totals

(2) Equipment maintenance events

(3) System consumables

(4) Steam production

(5) Solid waste processing

(6) Ash removal

A discussion of the collection and usage of the required data is presented in Appendix A.

7.0 SYSTEM RAM ANALYSIS

The procedures developed for RAM analysis of the HRI system are aimed at generating three evaluative parameters: reliability, availability, and maintainability. These parameters are discussed in the following paragraphs.

7.1 Reliability

Reliability is the probability that an item or system will perform its intended function without failure for a specified time period under specified conditions. In terms of computing procedures it is expressed as R.

There are two elements to consider when determining reliability: mission time and Mean Time Between Failures.

7.1.1 Mission Time.

The "specified time period," as mentioned in the definition of reliability, is referred to as "mission time" and is defined as the time or scheduled duty period for which uninterrupted operation of the HRI installation is desired. In terms of calculating procedures, it is expressed as "t". The mission time for each HRI installation may vary due to operating budgets and workload requirements.

A typical HRI installation may have a mission time of 120 hours, which could be the time between planned lightup at midnight on Sunday and shutdown at midnight on Friday.

7.1.2 Mean Time Between Failures

Mean Time Between Failures is defined as the average number of hours of operating time accrued between equipment failures. See appendix A, page A-9 for discussion of failures. It is expressed as MTBF and is computed by dividing the total HRI operating time (t_a) by the total number of validated equipment failures (F_T) occurring during that period.

$$MTBF = t_a/F_T \tag{1}$$

where: MTBF = Mean Time Between Failures
t_a = Total system operating time over designated period
F_T = Total number of failures

7.1.3 Calculating Reliability

HRI system reliability is computed by applying the following equation to the pertinent data:

$$R = e^{-t/MTBF} \tag{2}$$

where: R = Reliability probability value
MTBF = Mean Time Between Failures
t = Mission time
e = Base of Naperian log system
(A constant value equal to 2.718)

Example computation: If an HRI system has an MTBF of 300 hours and a mission time of 120 hours then,

$$R = e^{-t/MTBF}$$
$$\ln R = \ln e^{-t/MTBF}$$
$$\ln R = \ln 2.718^{-120/300}$$
$$R = .67$$

The resulting reliability value in the example indicates that this HRI system would have a 67 percent chance (67 out of 100 times) of operating satisfactorily (without failure) for a mission time of 120 hours.

7.1.4 Mean Time Between Maintenance Events

Mean Time Between Maintenance Events is defined as the average number of hours of operating time accrued between maintenance events. See appendix A, page A-9 for discussion of maintenance events. It is expressed as MTBME, and is computed by dividing the total HRI system operating time (t_a) by the total number of validated maintenance events (ME_T) occurring during that period.

$$MTBME = t_a/ME_T \tag{3}$$

where: MTBME = Mean time between maintenance events
t_a = Total HRI system operating time
ME_T = Total number of maintenance events

7.2 Availability

Operational availability is the probability that an item will be capable of performing its specified function when called upon to do so at any random point in time. It considers all forms of HRI system downtime. It is computed by determining the ratio of system operating time (t_a) to system downtime (DT). See appendix A, page 4 for discussion of downtime. System operational availability is expressed as A_o and is derived by applying the following equation to the pertinent data:

$$A_o = t_a/(t_a + DT) \tag{4}$$

where: A_o = Operational availability
t_a = Total system operating time
DT = Total system downtime

7.3 Maintainability

Maintainability is the inherent characteristic of a design or installation that determines the ease, economy, safety, and accuracy with which maintenance can be performed and that such a failed system or equipment therein can be restored to a specified operational condition.

There are a number of analytical expressions that indicate maintainability. The type of maintainability indicators that are most appropriate for HRI system evaluation are presented in the following paragraphs.

7.3.1 Mean Time To Repair

Mean Time To Repair is the average corrective maintenance time spent to correct a validated equipment failure. It is expressed as MTTR and is computed by dividing the total amount of corrective maintenance time (calendar hours) accrued by the total number of validated equipment failures.

$$MTTR = t_c/F_T \tag{5}$$

where: MTTR = Mean Time To Repair
t_c = Corrective maintenance time
F_T = Total number of system failures

7.3.2 Routine Maintenance Ratio

The routine maintenance ratio is the number of calendar hours spent performing routine maintenance per hour of system operate time. It is expressed as RMR and is computed by dividing the total amount of routine maintenance time by the total system operating time.

$$RMR = t_b/t_a \tag{6}$$

where: RMR = Routine maintenance ratio
t_a = Total system operating time
t_b = Total routine maintenance time

7.3.3 Corrective Maintenance Ratio

The corrective maintenance ratio is the number of calendar hours spent performing corrective maintenance per hour of system operating time. It is expressed as CMR and is calculated by dividing the total amount of corrective maintenance time by the total system operating time.

$$CMR = t_c/t_a \tag{7}$$

where: CMR = Corrective maintenance ratio
t_a = Total system operating time
t_c = Total corrective maintenance time

7.3.4 Maintainability Index

The maintainability index is the number of hours spent performing both corrective and routine maintenance per hour of system operating time. It is expressed as MI and is computed by dividing the total amount of corrective and routine maintenance by the total system operating time.

$$MI = (t_b + t_c)/ta \tag{8}$$

where:
MI = Maintainability index
t_a = Total system operating time
t_b = Total routine maintenance time
t_c = Total corrective maintenance time

8.0 SUBSYSTEM ANALYSIS

The procedures for RAM analysis presented in Section 7.0 discuss application to the HRI system from an overall system approach, whereby operation, maintenance, and failure data are attributed to the HRI system as one unit.

Analysis of HRI subsystem performance is accomplished by applying the same principles, except that overall system operating time and maintenance event data are broken down and assessed by each subsystem. Subsystem performance is demonstrable in this way because HRI subsystems can operate somewhat independently from each other for varying durations, depending on overall system demand.

The HRI system is divided into four basic subsystems:

(1) Solid Waste Receiving and Processing - Includes all equipment required for receiving, processing, storing, and readying solid waste for incineration (e.g., loader, overhead crane, flail mill, separators, storage containers, feed conveyors).

(2) Incineration - Includes all equipment required for burning solid waste (e.g., incinerator, fuel feed system).

(3) Ash Removal - Includes all equipment required for removing and collecting ash from the incinerator (e.g., conveyors, storage containers).

(4) Steam Generation - Includes all equipment required for steam production (e.g., boiler, deaerator, draft fan system).

Prior to evaluation, criteria must be developed that define subsystem boundaries. Development of criteria depends largely on the unique operating characteristics and design of the equipment being used and must be established accordingly.

8.1 Data Collection

Two forms of data are required for HRI subsystem analysis: (1) subsystem operating time, and (2) maintenance event data.

The accurate measurement of operating time for the four HRI subsystems is difficult because of the variety of methods and equipment that are available to perform each function. Operating time measurement may involve the installation of run-time meters on subsystem equipment that will best indicate subsystem operating time. Meter placement is dependent upon the operating principles and configuration of the equipment being used. Manual recording techniques can also be used to collect subsystem operating time.

See appendix B for discussion of forms used for collecting subsystem data.

8.1.1 Subsystem Operating Time

Subsystem operating time for any HRI start-up/shutdown cycle is determined by subtracting the pertinent subsystem meter reading at the time of system start-up (lines 4-7, FORM 1) from the meter reading at the time of system shutdown (lines 5-8, FORM 2). These operating times are totalled on a weekly basis and recorded in the SUBSYSTEM OPERATING TIME blank on the weekly FORM 5. Summing the weekly totals for the evaluation period provides the total subsytem operating time and is used to determine subsystem reliability, availability and maintainability parameters.

8.1.2 Subsystem Maintenance Data

The maintenance data required to perform subsystem analysis is extracted from the corrective and routine maintenance forms collected over the course of the evaluation period. The relevant subsystem classification is indicated on line 5 of FORM 3 (Corrective Maintenance) and FORM 4 (Routine Maintenance). These data are used to develop the Maintenance Event Summary which provides a reference for determining the total number of failures, total number of maintenance actions, and total amount of corrective maintenance time specific to each subsystem. The total routine maintenance time for each subsystem is determined by totalling all the appropriate routine maintenance times recorded on the FORM 4 collected over the course of the evaluation period.

8.2 Subsystem Data Analysis

There are two basic approaches to subsystem analysis. One is to evaluate the performance of each subsystem independently from the others. The second is to evaluate the performance of certain subsystem combinations.

8.2.1 Independent Subsystem Analysis

Independent subsystem analysis is performed by following the same procedures for overall HRI system analysis presented in Section 7.0, except that overall HRI system data is replaced by subsystem data.

8.2.2 Interactive Subsystem Analysis

Interactive subsystem analysis is performed by following the same procedures for overall HRI system analysis presented in Section 7.0, except that overall HRI system data is replaced with HRI subsystem combination mode data.

This type of analysis creates and evaluates three functional modes of overall HRI operation. Each mode consists of a particular combination mode of subsystem involvement.

The subsystem make-up and definition of each mode is illustrated by the following classification system:

(1) Processing subsystem

(2) Incineration subsystem

(3) Ash removal subsystem

(4) Steam generation subsystem

Mode A - Incinerate and produce steam with solid waste. Mode A analysis considers performance data from subsystems 1-4.

Mode B - Incinerate solid waste. Mode B analysis considers performance data from subsystems 1-3 only.

Mode C - Produce steam without solid waste. Mode B analysis considers performance data from subsystems 2 and 4 only.

HRI subsystems can function somewhat independently from each other, operating intermittently and for varying durations. Because of these performance characteristics, each subsystem will generate a unique total operating time and number of failures, thus creating a unique MTBF or failure rate. Subsystem failure rate (λ) is equal to 1/(Subsystem MTBF) and is expressed as failures per 10^6 hr. Subsystem failure rates are used to compute mode MTBF and R by the following methods.

(1) Mean Time Between Failures:

$$MTBF_A = \frac{1\ (10^6\ hr)}{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4} \tag{9}$$

where:
- $MTBF_A$ = Mode A MTBF
- λ_1 = Failure rate of subsystem 1
- λ_2 = Failure rate of subsystem 2
- λ_3 = Failure rate of subsystem 3
- λ_4 = Failure rate of subsystem 4

$$MTBF_B = \frac{1\ (10^6\ hr)}{\lambda_1 + \lambda_2 + \lambda_3} \tag{10}$$

where: $MTBF_B$ = Mode B MTBF

$$MTBF_C = \frac{1\ (10^6\ hr)}{\lambda_2 + \lambda_4} \tag{11}$$

where: $MTBF_C$ = Mode C MTBF

(2) Reliability:

$$R = e^{-t/MTBF_A} \tag{12}$$

where:
- R_A = Mode A reliability value
- e = Base of Naperian logarithm system
- t = Mission time (equal to system mission time)
- $MTBF_A$ = Mode A MTBF

$$R_B = e^{-t/MTBF_B} \tag{13}$$

where: R_B = Mode B reliability value

$$R_C = e^{-t/MTBF_C} \tag{14}$$

where: R_C = Mode C reliability value

9.0 LONG-TERM THERMAL EFFICIENCY

The thermal efficiency value determined for the HRI system indicates how many Btus in the form of steam energy are produced per Btu of energy input in the form of solid waste, fuel oils, and make-up water.

The long-term thermal efficiency of the HRI system is determined by applying the following equation to pertinent data:

$$TE = \frac{H_s}{H_{sw} + H_{fo} + H_w} \tag{15}$$

where:
- TE = Thermal efficiency
- H_{fo} = Total energy input from fuel oils (MBTU)
- H_s = Total energy output as steam (MBTU)
- H_{sw} = Total energy input from solid waste (MBTU)
- H_w = Total energy derived from make-up water (MBTU)

9.1 Energy Output as Steam

The energy output as steam generated by the HRI system is determined by multiplying the total quantity of steam produced by the difference of the enthalpy of steam and the enthalpy of water.

$$H_s = (h_s - h_w) \times M_8/10^6 \tag{16}$$

where:
- H_s = Energy output as steam (MBTU)
- h_s = Enthalpy of steam (Btu/lb)
- h_w = Enthalpy of water (Btu/lb)
- M_8 = Total quantity of steam produced (lb)

Note: The enthalpy of steam is a function of temperature and pressure and can be determined once these variables are known. Reference: Society for Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), "Handbook of Fundamentals," 1972.

9.2 Energy Input From Solid Waste

The energy input from the combustion of solid waste is determined by multiplying the total quantity of solid waste incinerated by the Higher Heating Value (HHV) of the solid waste.

$$H_{sw} = h_{sw} \times M_4/10^6 \tag{17}$$

where: H_{sw} = Energy derived from solid waste (MBTU)
h_{sw} = HHV of solid waste (Btu/lb)
M_4 = Total solid waste incinerated (lb)

Due to the variation in type and proportion of all component materials, the HHV of solid waste will vary. The standard methods for sampling and determining the HHV of solid waste are outlined in the American Society of Mechanical Engineers (ASME) Power Test Codes (PTC) publication number 33 and are provided in detail in the American Society for Testing and Materials (ASTM) standards E3801 and D2015.

9.3 Energy Input From Make-up Water

The energy input from make-up water is determined by multiplying the total quantity of make-up water consumed by the enthalpy of water.

$$H_w = h_w \times M_7/10^6$$

where: H_w = Energy input from make-up water (MBTU)
h_w = Enthalpy of water (Btu/lb)
M_7 = Total quantity of steam produced (lb)

Note: The enthalpy of water is a function of temperature and pressure and can be determined once these variables are known. Reference: American Society for Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), "Handbook of Fundamentals," 1972.

9.4 Energy Input From Fuel Oils

The energy input from fuel oils consumed by the HRI is determined by summing the total energy values of all the auxiliary fuels required to fuel the primary and secondary burners. The following equation includes the use of some common fuels.

$$H_{fo} = Aux_1 + Aux_2 + Aux_3 + \dots \tag{18}$$

where: H_{fo} = Energy derived from fuel oils (MBTU)
Aux_1 = Energy input from aux. fuel No. 1 (e.g., diesel oil)
Aux_2 = Energy input from aux. fuel No. 2 (e.g., No. 2 fuel oil)
Aux_3 = Energy input from aux. fuel No. 3 (e.g., waste oil)

$$Aux_1 = h_{do} \times DO_T/10^6 \tag{19}$$

where: Aux_1 = Energy input from diesel oil (MBTU)
h_{do} = HHV of diesel oil (Btu/gal)
DO_T = Total quantity of diesel oil consumed (gal)

$$Aux_2 = h_{fo} \times FO_T/10^6 \tag{20}$$

where: Aux_2 = Energy input from No. 2 fuel oil (MBTU)
h_{fo} = HHV of No. 2 fuel oil (Btu/gal)
FO_T = Total quantity of No. 2 fuel oil consumed (gal)

$$Aux_3 = h_{wo} \times WO_T/10^6 \tag{21}$$

where: Aux_3 = Energy input from waste oil (MBTU)
h_{wo} = HHV of waste oil (Btu/gal)
WO_T = Total quantity of waste oil consumed (gal)

Due to the variation in the type and proportion of all component materials, the HHV of waste oil will vary. The standard methods for sampling and determining the HHV of waste oil are provided in the ASME PTC 3.1, PTC 19.16, PTC 19.17, and ASTM standard D240.

9.5 Fossil Fuel Offset

The Fossil Fuel Offset (FFO) parameter is used to determine the potential energy savings from incinerating solid waste. The FFO parameter is calculated by subtracting the quantity of fossil fuels consumed by the HRI from the quantity of fossil fuels saved by the HRI. The quantity of fossil fuels consumed (Btu) is equal to the sum of the fuel oil, electricity, and make-up water energy sources input to the HRI. The quantity of fossil fuels saved (Btu) is equal to the steam energy produced by the HRI divided by the thermal efficiency of the boiler. The FFO parameter is expressed in barrels of oil equivalent (BOE) and is determined by applying the following equation to the pertinent data.

$$FFO = \frac{FF_B - FF_H}{5.8 \text{ MBTU/BOE}}$$

where: FFO = Fossil fuel offset (BOE)
FF_B = Fossil fuel energy saved (MBTU)
FF_H = Fossil fuel energy consumed (MBTU)
MBTU/BOE = One million Btu per BOE

$$FF_B = \frac{M_8 \times h_s}{TE_B \times 10^6}$$

where: FF_B = Fossil fuel energy saved (MBTU)
M_8 = Total quantity of steam produced (lb)
h_s = Enthalpy of steam (Btu/lb)
TE_B = Thermal efficiency of boiler

$$FF_H = H_{fo} + H_e + H_w$$

where: FF_H = Fossil fuel energy consumed (MBTU)
H_{fo} = Total energy derived from fuel oils (MBTU)
H_e = Total energy derived from electricity (MBTU)
H_w = Total energy derived from make-up water (MBTU)

The total energy derived from fuel oils (H_{fo}) includes all fossil fuel oils consumed by the front-end loader and incinerator (e.g., waste oil, diesel oil).

10.0 LANDFILL REDUCTION

One of the two basic functions of the HRI system is to reduce the volume of solid waste that would otherwise be dumped as landfill. To measure the capability of the HRI system to reduce landfill volume, the percentage of landfill reduction (PLR) parameter is determined.

The PLR is determined by applying the following equation to the pertinent data:

$$PLR = 100 \left(1 - \frac{M_3 + M_5 + M_6}{M_1 + M_2}\right) \qquad (31)$$

where:
- PLR = Percent landfill reduction
- M_1 = Amount of solid waste not accepted (lb)
- M_2 = Amount of solid waste received (lb)
- M_3 = Amount of solid waste rejected (lb)
- M_5 = Amount of wet ash removed (lb)
- M_6 = Amount of fly ash removed (lb)

11.0 LONG-TERM COST EFFECTIVENESS

Long-term cost effectiveness is indicated by determining a set of parameters that demonstrates the relationship of the costs of operating the HRI installation to its steam output. The major cost effectiveness indicator for the HRI installation evaluation is the average cost of steam (ACS) and is equivalent to the sum of all operating, maintenance, and labor costs divided by the total amount of heat energy generated as steam. The derived value represents cost in dollars per MBTU. The long-term cost effectiveness or average cost of steam of the HRI system is determined by applying the following equation to the pertinent data:

$$ACS = SCR + SCC + SCL \qquad (24)$$

where: ACS = Average cost of steam ($/MBTU)
SCR = Specific cost of repairs ($/MBTU)
SCC = Specific cost of consumables ($/MBTU)
SCL = Specific cost of labor ($/MBTU)

Following is a discussion of the three subparameters to be calculated when determining long-term cost effectiveness of the HRI system.

11.1 Specific Cost of Repair

The specific cost of repair value represents the average cost of HRI repair parts per MBTU of steam generated by the HRI system. The specific cost of repair is determined by applying the following equation to the pertinent data:

$$SCR = \frac{CP_T \times 10^6}{H_s} \qquad (25)$$

where: SCR = Specific cost of repair
CP_T = Total cost of parts ($)
H_s = Energy derived from steam (MBTU)

11.2 Specific Cost of Consumables

The specific cost of consumables value represents the average cost of HRI consumables per MBTU of steam generated by the HRI system. The specific cost of consumables is determined by applying the following equation to the pertinent data:

$$SCC = \frac{TCC \times 10^6}{H_s} \qquad (26)$$

where:
SCC = Specific cost of consumables \$/MBTU
TCC = Total cost of consumables (\$)
H_s = Total heat energy of steam (Btu)

The total cost of consumables (TCC) is determined by summing the computed costs of each consumable item which requires knowledge of particular cost rates that depend on marketplace conditions. The total cost of each consumable item is derived by multiplying the given rate of charge by the total amount consumed.

$$TCC = FO_T(r) + W_T(r) + C_T(r) + O_T(r) + E_T(r) \qquad (27)$$

where:
TCC = Total cost of consumables
FO_T = Total amount of fuel oil consumed
E_T = Total amount of electricity consumed
W_T = Total amount of water consumed
C_T = Total amount of chemicals consumed
O_T = Total amount of other consumables consumed
r = Specific consumable cost rate

11.3 Specific Cost of Labor

The specific cost of labor represents the average cost of HRI labor wages (fully burdened) per MBTU of steam generated by the HRI system. The specific cost of labor is determined by applying the following equation to the pertinent data:

$$SCL = SCOL + SCML \qquad (28)$$

where:
SCL = Specific cost of labor
SCOL = Specific cost of operating labor
SCML = Specific cost of maintenance labor

There are two variables to be considered when determining SCL: the specific cost of operating labor and the specific cost of maintenance labor. Derivation of these values is discussed in the following paragraphs.

11.3.1 Specific Cost of Operating Labor

The SCOL figure represents the average cost of HRI operating labor wages (fully burdened) per one MBTU of steam generated by the HRI system. Operating labor wages include these wages expended for labor to sustain the HRI system during normal operation, t_a, and operational idle time, t_d.

The SCOL is determined by applying the following equation to the pertinent data:

$$SCOL = \frac{(TOM \times W_o)\ (10^6)}{H_s} \tag{29}$$

where: SCOL = Specific cost of operating labor ($/MBTU)
TOM = Total operating man-hours
W_o = Fully burdened wages of operating personnel ($/hr)
H_s = Energy derived from steam (MBTU)

The total operating man-hours figure is derived by summing the man-hours during t_a and t_d.

11.3.2 Specific Cost of Maintenance Labor

The SCML figure represents the average cost of HRI maintenance labor wages (fully burdened) per MBTU of steam generated by the HRI system. Maintenance labor wages include those wages expended for maintenance during routine maintenance, t_b, corrective maintenance, t_c, and non operational idle time, t_e.

The SCML is determined by applying the following equation to pertinent data:

$$SCML = \frac{(TMM - W_m)\ (10^6)}{H_s} \tag{30}$$

where: SCML = Specific cost of maintenance labor ($/MBTU)
TMM = Total maintenance man-hours
W_m = Fully burdened wages of maintenance personnel ($/hr)
H_s = Energy derived from steam (MBTU)

The specific cost of labor is derived by summing the resulting values of SCOL and SCML. The SCL value represents the average number of overall labor dollars spent to generate one million Btus of steam.

LIST OF ACRONYMS AND NOMENCLATURE

A_o	Operational availability
Aux_1	Energy input from diesel oil (MBTU)
Aux_2	Energy input from No. 2 fuel oil (MBTU)
Aux_3	Energy input from waste oil (MBTU)
ACS	Average cost of steam ($/MBTU)
Btu	British thermal unit
BOE	Barrel of oil equivalency
C_T	Total quantity of chemicals consumed (lb)
CMR	Corrective maintenance ratio (hr/hr)
CP_T	Total cost of replacement parts and materials ($)
DO_T	Total quantity of diesel oil consumed (gal)
DT	Downtime (hr)
e	Base of Naperian logarithm system
E_T	Total quantity of electrical power consumed (kw)
fo_T	Total quantity of no. 2 fuel oil consumed (gal)
F_T	Total number of HRI system failures
FF_B	Fossil fuel energy saved (MBTU)
FF_H	Fossil fuel energy consumed (MBTU)
FFO	Fossil fuel offset (BOE)
FO_T	Total quantity of fuel oils consumed (gal)
h_{do}	Higher heating value of diesel oil (Btu/gal)
h_{fo}	Higher heating value of no. 2 fuel oil (Btu/gal)
h_s	Enthalpy of steam (Btu/lb)
h_{sw}	Higher heating value of solid waste (Btu/lb)
h_w	Enthalpy of water (Btu/lb)

LIST OF ACRONYMS AND NOMENCLATURE (Continued)

h_{wo}	Higher heating value of waste oil (Btu/gal)
H_e	Energy derived from electricity (MBTU)
H_{fo}	Energy derived from fuel oils (MBTU)
H_s	Energy derived from steam (MBTU)
H_{sw}	Energy derived from solid waste (MBTU)
H_w	Energy derived from make-up water (MBTU)
HHV	Higher heating value
HRI	Heat recovery incinerator
λ	Failure rate (failures/10^6 hr)
ln	Natural logarithm
M	Maintainability
M_1	Total solid waste not accepted (lb)
M_2	Total solid waste received (lb)
M_3	Total solid waste rejected (lb)
M_4	Total solid waste incinerated (lb)
M_5	Total wet ash removed (lb)
M_6	Total fly ash removed (lb)
M_7	Total quantity of make-up water consumed (lb)
M_8	Total quantity of steam produced (lb)
Mt_a	Man-hours expended during HRI operating time
Mt_b	Man-hours expended during routine maintenance time
Mt_c	Man-hours expended during corrective maintenance time
MBTU	Mega Btu (one million Btus)
ME_T	Total number of maintenance events
MI	Maintainability index (hr/hr)

LIST OF ACRONYMS AND NOMENCLATURE (Continued)

MTBF	Mean Time Between Failures (hr)
MTBME	Mean Time Between Maintenance Events (hr)
MTTR	Mean Time To Repair (hr)
O_T	Total amount of "other" consumables
PLR	Percent landfill reduction
r	Specific consumable cost rate
R	Reliability
RAM	Reliability, availability, and maintainability
RMR	Routine maintenance ratio (hr/hr)
SCC	Specific cost of consumables ($/MBTU)
SCL	Specific cost of labor ($/MBTU)
SCML	Specific cost of maintenance labor ($/MBTU)
SCOL	Specific cost of operating labor ($/MBTU)
SCR	Specific cost of repair ($/MBTU)
t	Mission time (hr)
t_a	Operating time (hr)
t_b	Routine maintenance time (hr)
t_c	Corrective maintenance time (hr)
t_d	Operational idle time (hr)
t_e	Nonoperational idle time (hr)
T	Total calendar time duration of evaluation period (hr)
TCC	Total cost of consumables ($)
TE	Thermal efficiency
TMM	Total maintenance man-hours
TOM	Total operating man-hours

LIST OF ACRONYMS AND NOMENCLATURE (Continued)

W_m	Wages of maintenance personnel ($)
W_o	Wages of operating personnel ($)
W_T	Total amount of water consumption (gal)
WO_T	Total quantity of waste oil consumed (gal)

APPENDIX A

SYSTEM TIME CATEGORIES

AND DETAILED DATA

COLLECTION INSTRUCTIONS

A. System Time Categories

RAM analysis of the HRI system requires the statistical manipulation of the time periods associated with various equipment operation and maintenance conditions. These time categories are illustrated by the following equation:

$$T = t_a + t_b + t_c + t_d + t_e$$

where: T = Total calendar time duration of evaluation period

t_a = Total HRI system operating time

t_b = Total routine maintenance time

t_c = Total corrective maintenance time

t_d = Total operational idle time

t_e = Total non-operational idle time

A graphic demonstration of the relationship of these time categories is presented in Figure 2. Further discussion is provided in the following paragraphs.

1. Mission Time

Mission time is defined as the time period for which uninterrupted operation of the HRI system is desired. It is based on a seven-day week (168 hr). In terms of calculating procedures, it is expressed as t and is used to determine system downtime and reliability.

2. System Operating Time

System operating time is the amount of time accumulated over the evaluation period during which the HRI system is performing its intended operating function. In terms of calculating procedures, it is expressed as t_a.

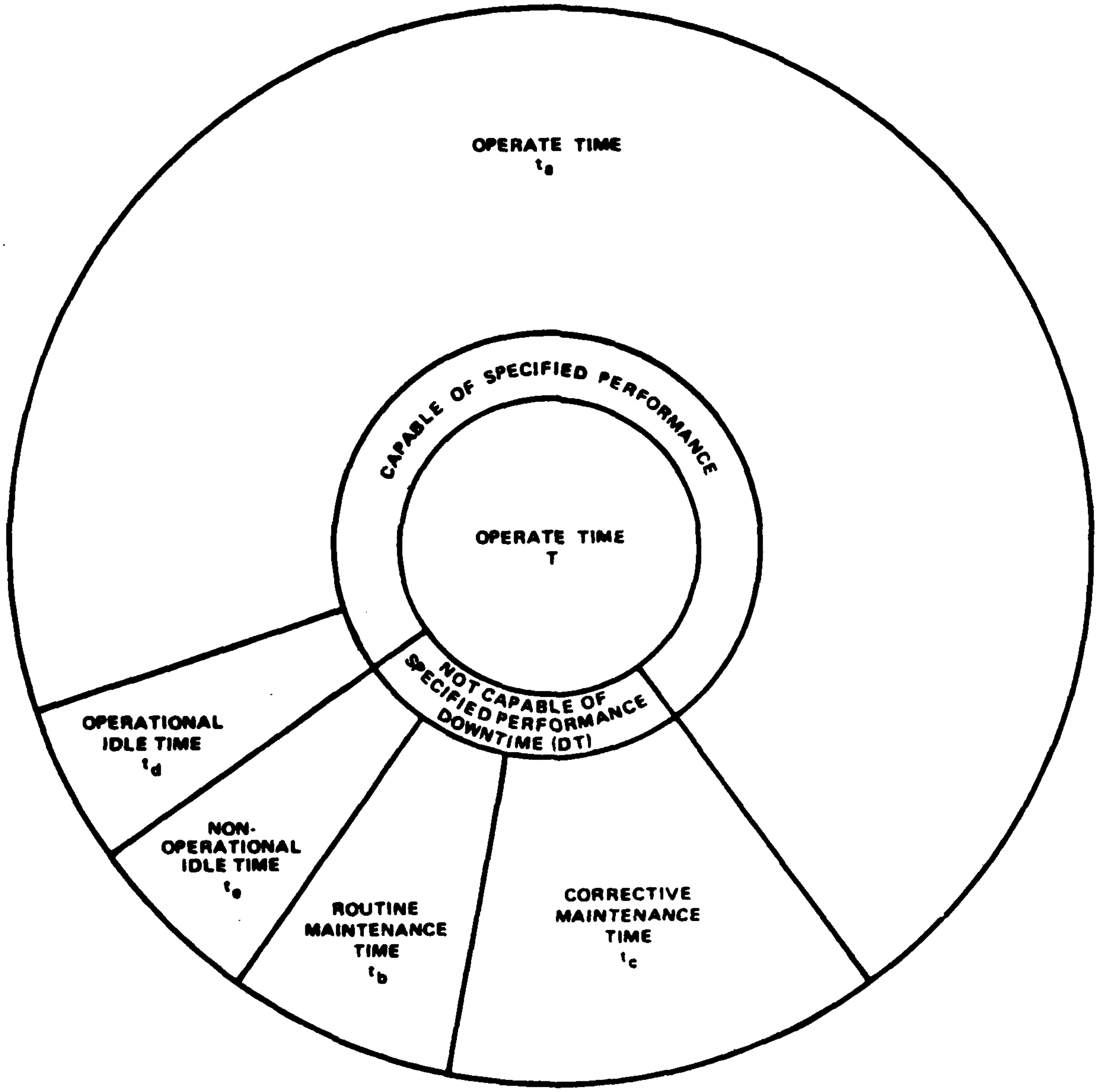

Figure 2. HRI Operation and Maintenance Time Categories

The system operating time is either entered into the steam plant log or measured by a run-time meter connected to the "power on" circuit of the draft fan motor. The draft fan is turned on after the system has undergone its warm-up phase and turned off when system cool-down is completed. The duration of system warm-up and cool-down times are dictated by the unique operating characteristics of each HRI system. The time accumulated on the draft fan run-time meter during the cool-down period is not considered as system operating time.

The operating time for any given HRI start-up/shutdown cycle is determined by subtracting the draft fan run-time meter reading at system start-up (line 3 of FORM 1) from the draft fan run-time meter reading at system shutdown (line 3 of FORM 2). These operating time periods are totalled on a weekly basis and recorded in the OPERATING TIME blank on the weekly FORM 5. Summing the weekly totals for the designated evaluation period provides t_a, which is used to calculate the system Mean Time Between Failures (MTBF) and reliability.

3. System Downtime

System downtime, as it relates to the HRI system, is defined as the portion of time that equipment is intended to operate during which equipment is not in condition to fulfill its intended function.

Downtime (DT) is determined on a weekly basis by subtracting the sum of the OPERATING TIME entry and the OPERATIONAL IDLE TIME entry on the weekly FORM 5 from the HRI system mission time (168 hr). This figure is then recorded in the DOWNTIME blank on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period and are used to determine operational availability of the HRI system.

4. Routine Maintenance

Routine maintenance time is the amount of time accumulated during which planned preventive maintenance is performed to retain equipment in satisfactory operating condition or to improve operating condition. Routine maintenance time consists of only time during which scheduled preventive maintenance is performed (i.e., planned maintenance that is required and critical for HRI system operation). It does not include "might as well" preventive maintenance performed during periods of corrective maintenance or preventive maintenance performed as "busy work."

As it relates to the process of data collection and analysis, it is assumed that routine and corrective maintenance are not performed concurrently; therefore, the associated time categories are mutually exclusive. Routine maintenance includes the following scheduled maintenance tasks:

(1) Inspection

(2) Adjustment

(3) Lubrication

(4) Cleaning

(5) Overhaul

(6) Modification

When a routine maintenance task is performed, an account of the action is recorded on FORM 4. The events that occurred, time to complete, manpower involved, and appropriate dates are recorded on this form.

Subtracting the TIME MAINTENANCE STARTED entry from the TIME MAINTENANCE COMPLETED entry on FORM 4 will provide the time spent performing routine maintenance for one event. A total of routine maintenance times is determined on a weekly basis and recorded in the ROUTINE MAINTENANCE blank on the weekly FORM 5.

Summing the weekly totals for the designated evaluation period provides t_b, which is used to compute maintainability and long-term cost effectiveness of the HRI system.

5. Corrective Maintenance

Corrective maintenance time is the amount of time accumulated during which corrective maintenance is performed to restore equipment to the specified performance level. Corrective maintenance includes:

(a) Troubleshooting

(b) Disassembly

(c) Part interchange and repair

(d) Reassembly

(e) Adjustment/checkout

When a corrective maintenance action occurs, an account of the action is recorded on FORM 3. The events that occurred, time to complete, manpower involved, and appropriate dates are recorded on this form.

Subtracting the TIME MAINTENANCE STARTED entry from the TIME MAINTENANCE COMPLETED entry on FORM 3 will provide the time spent performing corrective maintenance for one event. A total of the corrective maintenance times is determined on a weekly basis and recorded in the CORRECTIVE MAINTENANCE blank on the weekly FORM 5. Summing the weekly totals for the designated evaluation period provides t_c, which is used to compute maintainability and long-term cost effectiveness.

6. Idle Time

(a) Operational Idle Time

Operational idle time is the amount of time accumulated during which the HRI could have been operated, but was not operated for one or more of the following reasons:

- Following completion of routine or corrective maintenance shutdowns when time accrues before the next HRI start-up
- For reasons other than routine or corrective maintenance shutdown cycles such as off-duty periods on weekends or holidays

Operational idle time is determined by comparing the HRI system operating and maintenance periods, which are indicated on the designated forms.

Subtracting the TIME MAINTENANCE COMPLETED entry on FORM 4 from the TIME HRI LIGHTED entry on the FORM 1 for the next scheduled start-up will provide the operational idle time between one routine maintenance shutdown period and the next HRI start-up. Subtracting the TIME MAINTENANCE COMPLETED entry on FORM 3 from the TIME HRI LIGHTED entry on the FORM 1 for the next scheduled start-up will provide the operational idle time between one corrective maintenance shutdown period and the next HRI start-up.

The periodic accumulation of operational idle times is totalled on a weekly basis. The total figures are recorded in the OPERATIONAL IDLE TIME blank on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period, providing t_d, which is used to calculate long-term cost effectiveness of the HRI system.

(b) Nonoperational Idle Time

Nonoperational idle time is the amount of time accumulated during which the HRI is in shutdown mode due to routine or corrective maintenance, is not experiencing maintenance, and could not have been operated. These periods include:

- Time spent cooling the HRI to commence routine or corrective maintenance
- Time spent procuring and waiting for replacement items.

Nonoperational idle time is determined by examining the HRI system routine and corrective maintenance periods, which are indicated on the designated forms.

The MAINTENANCE DELAY TIME entry on FORM 3 indicates nonoperational idle time and is subject to the judgment of maintenance personnel. The MAINTENANCE DELAY TIME entries are totalled on a weekly basis. The total figures are recorded in the NONOPERATIONAL IDLE TIME blank on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period, providing t_e, which is used to calculate long-term cost effectiveness of the HRI system.

7. Man-hours

Man-hours data is the amount of time expended per man to perform a given task (e.g., if two men work eight hours on corrective maintenance, 16 man-hours are expended to perform the task involved). Man-hours data is collected for each mode of maintaining the HRI system that requires the involvement of personnel. These data are required to determine the cost of manpower to operate the HRI system, consequently having a bearing on the long-term cost effectiveness of the installation.

In terms of calculating procedures, man-hours data is expressed as:

(a) Mt_a - Man-hours expended during normal operating cycle of HRI

(b) Mt_b - Man-hours expended during routine maintenance

(c) Mt_c - Man-hour expended during corrective maintenance

For each mode of HRI operation and maintenance, there is an appropriate form of documentation used to record the time involved in which the HRI system experiences that mode. Each form also has space provided for recording the man-hours expended by plant personnel to support the associated mode of operation. The man-hour figures are totalled on a weekly basis. The weekly totals are recorded in the MAN-HOURS totals section on the weekly FORM 5. Summing the weekly totals for each category of HRI operation for the designated evaluation period will provide Mt_a, Mt_b, and Mt_c, which are used to calculate long-term cost effectiveness of the HRI system.

B. Maintenance Event Summary

An important aspect of evaluating the HRI system is the collection and recording of data related to equipment malfunctions.

Equipment malfunctions that occur over the course of the evaluation period are recorded on FORM 3 (see Appendix B). At the time of HRI system evaluation, these forms are examined to determine the validity of the recorded equipment malfunctions, or "maintenance events." The maintenance events are then classified as either a failure (F) or a maintenance action (MA).

For the purpose of HRI RAM evaluation, a failure is defined as a maintenance event that involves a severe deterioration, break, or wear-out of a component part that degrades equipment operation below specified levels, and which requires repair or replacement of the component part. A maintenance action includes any maintenance event that requires the readjustment or unjamming of a component part to restore equipment to a specified level of operation.

The distinction between failures and maintenance actions becomes significant when calculating final RAM parameters. Failures only are considered for all major RAM parameters except Mean Time Between Maintenance Events (MTBME), which includes both failures and maintenance actions.

The validated and classified list of maintenance events is arranged chronologically in the form of a table and is referred to as the "Maintenance Event Summary" (see Appendix C). The Maintenance Event Summary table provides the data analyst with the date, classification, repair time, failed part, and circumstances associated with each maintenance event. Thus, it provides a data reference for calculating final HRI RAM parameters.

C. System Consumables

The HRI installation requires certain services and material to sustain operation. These input items must be measured to accurately determine cost effectiveness and thermal efficiency of the HRI system.

1. Water

Water serves three basic functions for the HRI installation: to provide boiler feedwater, to treat ash remaining from the incineration process, and to provide firefighting, maintenance, and personnel subsistence needs. It is supplied to the HRI plant by conventional methods employed by the local water company.

Overall HRI installation water consumption is measured by a flow meter at some point prior to the plant water network. Meter readings are recorded on a weekly basis in the CONSUMABLES section on the weekly FORM 5. The weekly figures are totalled for the evaluation period, providing W_T, which is used to determine operating cost and long-term cost effectiveness of the HRI system.

(a) <u>Make-up Water</u>

Make-up water is boiler feedwater that undergoes a softening or, occasionally, a demineralization process. Make-up water consumption is measured by a flow/totalizer meter installed at the make-up water tank outlet to the deaerator and boiler. Make-up water meter readings are recorded at the time of system start-up on FORM 1 and system shutdown on FORM 2. The operating cycle figures are totalled on a weekly basis and recorded in the MAKE-UP WATER blank on the weekly FORM 5.

The weekly figures for make-up water consumption are totalled for the designated evaluation period, providing M_7, which is used to determine thermal efficiency of the HRI system.

2. <u>Electrical Power</u>

Overall HRI installation power consumption is measured by a wattmeter installed on appropriate panels at some point prior to the plant electrical network. Meter readings are recorded on a weekly basis in the CONSUMABLES section on the weekly FORM 5. The weekly figures are totalled for the evaluation period, providing E_T, which is used to determine operating cost, long-term cost effectiveness, and thermal efficiency of the HRI system.

3. <u>Water Treatment Chemicals</u>

Make-up water which is fed to the boiler to produce steam must first undergo softening, or occasionally a demineralization process which requires the use of salt. In some cases, the feedwater must then be treated with certain chemicals to control alkalinity and oxygen content.

The quantities of these chemicals used by the treatment of make-up water are recorded at the end of each system operating period in the CONSUMABLES section on FORM 2. These figures are totalled on a weekly basis and entered in the CONSUMABLES section on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period, providing C_T, which is used to determine operating cost and long-term cost effectiveness of the HRI system.

4. <u>Fuels</u>

Various fuels are required for two HRI functions: operation of the front-end loader, and firing the burners in the primary and secondary combustion chambers of the incinerator.

A variety of fuels can be used to power both HRI functions. These may include: diesel fuel, no. 2 fuel oil, waste oil, and natural gas.

The quantity of fuel supplied to the front-end loader can be measured at the fuel pump or by examination of filling containers by operating personnel. These quantities are recorded at the end of each system operating period in the LOADER FUEL blank on FORM 2. These figures are totalled on a weekly basis and are recorded in the LOADER FUEL blank on the weekly FORM 5.

Provision of fuel to the incinerator burners is measured by a meter at the fuel tank. The fuel flow/totalizer meter is read at the beginning and end of each operating period and recorded in the BURNER FUEL METER blanks on

FORM 1 and 2. These figures are totalled on a weekly basis and recorded in the BURNER FUEL METER blanks on the weekly FORM.

The weekly figures for all fuel consumption are totalled for the designated evaluation period, providing FO_T, which is used to determine operating cost, long-term cost effectiveness, and thermal efficiency of the HRI system.

5. Other Consumables

A variety of other supplies are required to maintain HRI system operation. These materials may include: lubricating oil, hydraulic fluid, and cleaning agents. The quantity of these materials used is recorded at the end of each system operating period in the CONSUMABLES section on FORM 2. These figures are totalled on a weekly basis and recorded in the CONSUMABLES section on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period, providing O_T, which is used to determine operating cost and long-term cost effectiveness of the HRI system.

6. Replacement Parts and Materials

Replacement parts and materials required to repair certain HRI equipment failure conditions are monitored to determine HRI system operating costs.

The cost of various replacement parts for HRI equipment is determined on a monthly basis by examining billing records and/or various organizational supply catalogs. The cost of replacement part figures are totalled on a weekly basis and entered in the CONSUMABLES section on the weekly FORM 5. The weekly figures are totalled for the evaluation period, providing CP_T, which is used to determine long-term cost effectiveness of the HRI system.

E. Steam Production

The generation of steam is one of the two basic functions of the HRI system. To evaluate the capability and efficiency of the HRI system to fulfill this function, steam production is measured.

Steam production is measured by a flow/totalizer meter at the point of steam output from the boiler. The steam output meter reading is recorded at the time of system start-up on FORM 1 and system shutdown on FORM 2.

Subtracting the STEAM FLOW METER entry on FORM 1 from the STEAM FLOW METER entry on FORM 2 will provide the amount of steam in pounds generated for a given operating period. These operating period figures are totalled on a weekly basis and entered in the STEAM FLOW blank on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period, providing M_8, which is used to calculate long-term thermal efficiency and long-term cost effectiveness of the HRI system.

F. Solid Waste Processing

Control and measurement of the solid waste materials processed by the plant is important to HRI system evaluation. Since each HRI plant is different, with its own unique set of operating requirements and terminology, the daily log should be designed at the HRI plant by the actual users. The values on the daily log may then be used to update the information on the weekly logs. HRI system evaluation of the solid waste materials processed by the plant involves four specific categories of measurement, which are discussed in the following paragraphs.

1. Solid Waste Not Accepted

Solid waste materials arrive at the plant by vehicle and are weighed on a conventional truck scale. If the plant is not operational, the load of solid waste may have to be delivered to a landfill site, bypassing the HRI plant. The measured weight of this load of solid waste is recorded on a daily log designated SOLID WASTE NOT ACCEPTED. The daily logs are reviewed and the totals calculated on a weekly basis. The totals are recorded in the SOLID WASTE NOT ACCEPTED blank on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period, providing M_1, which is used to determine the percent landfill reduction parameter for the HRI system.

2. Solid Waste Received

If the HRI plant is operational, the load of measured incoming solid waste is dumped on the tipping floor for sorting. The measured weight of this load of solid waste is recorded on a daily log designated SOLID WASTE RECEIVED. The daily logs of solid waste received are reviewed and the totals calculated on a weekly basis. The totals are recorded in the SOLID WASTE RECEIVED blank on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period providing M_2, which is used to determine the percent landfill reduction parameter for the HRI system.

3. Solid Waste Rejected

Solid waste materials are dumped on the tipping floor where they are sorted for materials that are unsuitable for incineration. At some installations, a front-end mechanical processing system performs this task prior to incineration. At other installations, it may be done by skip loader, loader-grapple, overhead crane, by hand, or any combination thereof.

Regardless of the method used for sorting out materials unsuitable for incineration, the extracted solid waste materials are collected in various storage bins. The extracted solid waste material is loaded on a vehicle, weighed on a conventional truck scale, and delivered to a landfill site. The measured weight of this solid waste is recorded on a daily log designated SOLID WASTE REJECTED.

The daily logs of solid waste rejected are reviewed and the totals calculated on a weekly basis. The totals are recorded in the SOLID WASTE REJECTED blank on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period, providing M_3, which is used to determine the percent landfill reduction parameter for the HRI system.

4. Solid Waste Incinerated

The amount of solid waste that is actually incinerated is determined by subtracting the amount of solid waste rejected (M_3) from the amount of solid waste received (M_2). In terms of calculating procedures it is expressed as M_4 and is used to calculate the total heat energy of solid waste input and to determine long-term thermal efficiency of the HRI system.

5. Wet Ash Removal

Wet ash remaining from the incineration of solid waste materials is removed from the quench tank by a drag mechanism, then drained and dumped into a storage container. The wet ash container is loaded on a vehicle, weighed on a conventional truck scale, and delivered to a landfill site. The measured weight of the wet ash is recorded on a daily log designated WET ASH REMOVED.

The daily logs of wet ash removed are reviewed and the totals calculated on a weekly basis. The totals are recorded in the WET ASH REMOVED blank on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period, providing M_5, which is used to determine the percent landfill reduction parameter for the HRI system.

6. Fly Ash Removal

The fine ash that flies away from the burning solid waste materials is drafted out of the incinerator and collected in a storage container. The fly ash container is loaded on a vehicle, weighed on a conventional truck scale, and delivered to a landfill site. The measured weight of the fly ash is recorded on a daily log designated FLY ASH REMOVED.

The daily logs of fly ash removed are reviewed and the totals calculated on a weekly basis. The totals are recorded in the FLY ASH REMOVED blank on the weekly FORM 5. The weekly figures are totalled for the designated evaluation period, providing M_6, which is is used to determine the percent landfill reduction parameter for the HRI system.

APPENDIX B

DATA COLLECTION FORMS

AND INSTRUCTIONS

A. FORM 1 - START-UP/RESTART

FORM 1 is used for recording operating data prior to scheduled HRI start-ups, or restarts following unscheduled shutdowns.

1. Prior to HRI lightoff, record the date (line 1) and all specified meter readings (lines 3-11).
2. Record the time of HRI lightoff (line 2).
3. If HRI lightoff or start-up is unsuccessful due to a malfunction or failure, proceed to fill out the corrective maintenance FORM 3.

B. FORM 2 - SHUTDOWN

FORM 2 is used for recording operating data following shutdown of the HRI system.

1. Record the date and time the HRI is shutdown (lines 1 and 2). Shutdown is not complete until system cool-down is achieved and the draft fan is turned off.
2. Record the reason for shutdown on line 15 (scheduled shutdown, malfunction, etc).
3. Following completed shutdown, record all meter readings (lines 3-12).
4. Refer to the DATE and TIME HRI LIGHTED entries (lines 1 and 2) on the previous start-up FORM 1. Compare this time with the subsequent DATE and TIME HRI SHUTDOWN (lines 1 and 2) entries on FORM 2 and determine man-hour totals for the three categories of operating personnel during this period. Record these totals on line 4.
5. Refer to the DATE and TIME HRI LIGHTED entries (lines 1 and 2) on the previous start-up FORM 1. Compare this time with the subsequent DATE and TIME HRI SHUTDOWN entires (lines 1 and 2) on FORM 2 and determine the quantities of loaded fuel and consumables used during this period. Record the totals on lines 13 and 14.

C. FORM 3 - CORRECTIVE MAINTENANCE

FORM 3 is used for recording corrective maintenance data related to equipment malfunction and failure. Use a new form for each corrective maintenance task.

Corrective maintenance action includes:

a. Troubleshooting

b. Disassembly

c. Part readjustment, repair, or interchange

d. Reassembly

e. Adjustment/checkout

1. FORM 2 (SHUTDOWN) must be completed before corrective maintenance is performed.

2. If corrective maintenance is not performed immediately, describe the reason on line 8. When the maintenance delay time is determined, record it on line 7.

3. Describe the reason for corrective maintenance on line 8, including the malfunctioning or failed part.

4. Record the subsystem location of the malfunction or failure on line 5 using the following categorization:

   P - Processing

   I - Incineration

   R - Ash Removal

   S - Steam Generation

5. Record the date and time maintenance is started on line 1. When the time of maintenance completion is determined, record it on line 2.

6. Subtract line 1 from line 2 and record the total time of corrective maintenance on line 3.

7. Refer to the DATE/TIME MAINTENANCE STARTED entry on line 1. Compare this time with the DATE/TIME MAINTENANCE COMPLETED entry on line 2 and determine the man-hour totals for the three categories of maintenance personnel during this period. Record the totals on line 5.

D. FORM 4 - ROUTINE MAINTENANCE

Form 4 is used for recording routine maintenance data related to support of the HRI system. Use a new form for each corrective maintenance task.

Routine maintenance action includes:

a. Inspection

b. Adjustment

c. Lubrication

d. Cleaning

e. Overhaul

f. Modification

1. FORM 2 (SHUTDOWN) must be completed before routine maintenance is performed.

2. Describe the reason for routine maintenance on line 8.

3. Record the subsystem location where the routine maintenance is performed on line 5 using the following categorization.

   P - Processing

   I - Incineration

   R - Ash Removal

   S - Steam Generation

4. Record the date and time maintenance is started on line 1. When the time of maintenance completion is determined, record it on line 2.

5. Subtract line 1 from line 2 and record the total time of routine maintenance on line 3.

6. If completion of routine maintenance is delayed, describe the reason on line 7. When the maintenance delay is determined, record it on line 6.

7. Refer to the DATE/TIME MAINTENANCE STARTED entry on line 1. Compare this time with the DATE/TIME MAINTENANCE COMPLETED entry on line 2 and determine the man-hour totals for the three categories of maintenance personnel during this period. Record these totals on line 4.

E. <u>FORM 5 - WEEKLY DATA TOTALS</u>

FORM 5 is used for recording the weekly totals of all HRI operation and maintenance data.

1. Record the week ending date at the top of FORM 5.

2. Determine the total HRI system operating time accumulated during the week. Sum the operating time periods indicated by each set of FORMs 1 and 2 filled out during the week. Subtracting the system required cool-down time from the rate operating time to provide the actual operating time for that period. Record the total actual operating time periods for the week on line 1.

3. Determine the total HRI system operating time man-hours accumulated during the week. Sum the OPERATING TIME MAN-HOURS entries on line 4 of each FORM 2 filled out during the week. Record the totals on line 1.

4. Determine the total routine maintenance time accumulated during the week. Sum the TOTAL TIME OF ROUTINE MAINTENANCE entries on line 3 of each FORM 4 filled out during the week. Record the total on line 2.

5. Determine the total routine maintenance man-hours accumulated during the week. Sum the MAN-HOURS OF ROUTINE MAINTENANCE entries on line 4 of each FORM 4 filled out during the week. Record the totals on line 2.

6. Determine the total corrective mintenance time accumulated during the week. Sum the TOTAL TIME OF CORRECTIVE MAINTENANCE entries on line 3.

7. Determine the total corrective maintenance man-hours accumulated during the week. Sum the MAN-HOURS OF CORRECTIVE MAINTENANCE entries on line 4 of each FORM 3 filled out during the week. Record the totals on line 3.

8. Determine the total system operational idle time accumulated during the week. Total the weekly periods of:

   (1) Time between shutdown and next scheduled HRI start-up (weekends, holidays, etc.).

   (2) Time between the completion of corrective or routine maintenance and the next HRI start-up/restart.

   Subtract the TIME MAINTENANCE COMPLETED entries on line 2 of each FORM 3 and FORM 4 filled out during the week from the TIME HRI LIGHTED entry on line 2 of FORM 1 for the next HRI start-up. This is the total time between maintenance periods and next scheduled start-ups. Add to this the total time between scheduled shutdowns and scheduled start-ups (weekends, holidays, etc). Record the overall total on line 4, the total operational idle time.

9. Determine the total system nonoperational idle time accumulated during the week. Total the weekly periods of:

   (1) Time spent cooling the HRI to commence routine or corrective maintenance.

   (2) Time spent procuring and waiting for replacement items.

   Total the MAINTENANCE DELAY TIME entries on line 6 of each FORM 3 and FORM 4 filled out during the week. Add to this the totaled cool-down times associated with each maintenance shutdown that occured during the week. Record the overall total on line 5.

10. Determine total system downtime accumulated during the week. Subtract the weekly system operating time entry on line 1 from the HRI system mission time (1 week = 168 hr). Record the total on line 6.

11. Examine the daily logs for solid waste not accepted and compute the weekly total. Record the total on line 7.

12. Examine the daily logs for solid waste received and compute the weekly total. Record the total on line 8.

13. Examine the daily logs for solid waste rejected and compute the weekly total. Record the total on line 9.

14. Examine the daily logs for wet ash removed and compute the weekly total. Record the total on line 10.

15. Examine the daily logs for fly ash removed and compute the weekly total. Record the total on line 11.

16. Determine the total quantity of make-up water consumed for the week. Sum the intermediate make-up water quantities indicated by each set of FORMs 1 and 2 filled out during the week. Subtracting the MAKE-UP METER entry on line 9 of FORM 1 from the MAKE-UP WATER METER entry on line 10 of FORM 2 provides the steam output for the associated operating period. Sum the intermediate make-up water quantities for the week and record the total on line 13.

17. Determine the total HRI steam production for the week. Sum the intermediate steam outputs indicated by each set of FORMs 1 and 2 filled out during the week. Subtracting the STEAM FLOW METER entry on line 8 of FORM 1 from the STEAM FLOW METER entry on line 9 of FORM 2 provides the steam output for the associated operating period. Sum the intermediate steam outputs for the week and record the total on line 12.

18. Determine the total quantity of fuel oil consumed during the week. Sum the intermediate quantities of consumption indicated by each set of FORMs 1 and 2 filled out during the week. Subtracting the fuel meter entries on lines 10 and 11 of FORM 1 from the fuel meter entries on lines 11 and 12 of FORM 2 provides the quantity of fuel oil consumed for the associated operating period. Sum the intermediate quantities and record the total on lines 14 and 15.

19. Determine the total quantity of loader fuel consumed during the week. Sum the LOADER FUEL entries on line 13 of each FORM 2 that was filled out during the week. Record the total on line 16.

20. Determine the total quantities of consumables used during the week. Sum the CONSUMABLES entries on line 14 of each FORM 2 that was filled out during the week. Record the total on line 17.

21. Determine subsystem operating time, routine maintenance time, and corrective maintenance time. Follow the same procedures discussed in Steps 2, 4, and 6 of Section E of these instructions. Refer to subsystem data on all pertinent forms to make computations.

<u>FORM 1</u>

START-UP/RESTART

PAGE NO.______

1. DATE ....______m/day/yr
2. TIME HRI LIGHTED ....______hr/min
3. DRAFT FAN METER ....______hr
4. PROCESSING SUBSYSTEM METER ....______hr
5. INCINERATION SUBSYSTEM METER ....______hr
6. ASH REMOVAL SUBSYSTEM METER ....______hr
7. STEAM GENERATION SUBSYSTEM METER ....______hr
8. STEAM FLOW METER ....______lb
9. MAKE-UP WATER FLOW METER ....______gal
10. PRIMARY BURNER FUEL METER ....______gal
11. SECONDARY BURNER FUEL METER ....______gal

FORM 2

SHUTDOWN

PAGE NO.______

1. DATE ....______mo/day/yr
2. TIME HRI SHUTDOWN ....______hr/min
3. DRAFT FAN METER ....______hr
4. OPERATING TIME MAN-HOURS* ......PW______M/H C______M/H M______M/H
5. PROCESSING SUBSYSTEM METER ....______hr
6. INCINERATION SUBSYSTEM METER ....______hr
7. ASH REMOVAL SUBSYSTEM METER ....______hr
8. STEAM GENERATION SUBSYSTEM METER ....______hr
9. STEAM FLOW METER ....______lb
10. MAKE-UP WATER FLOW METER ....______gal
11. PRIMARY BURNER FUEL METER ....______gal
12. SECONDARY BURNER FUEL METER ....______gal
13. LOADER FUEL ....______gal
14. CONSUMABLES ....SO_3______lb

    PO_4______lb

    SALT ______lb

    OTHER ______
15. REASON FOR SHUTDOWN: ______________________________________

____

____

*MAN-HOURS: PW = Public Works personnel

C = Contractor personnel

M = Military personnel

FORM 3

CORRECTIVE MAINTENANCE

PAGE NO. ____

1. DATE/TIME MAINTENANCE STARTED ....______mo/day/yr ______hr/min
2. DATE/TIME MAINTENANCE COMPLETED ....______mo/day/yr ______hr/min
3. TOTAL TIME OF CORRECTIVE MAINTENANCE .... ______hr/min
4. MAN-HOURS OF CORRECTIVE MAINTENANCE* ....PW ______M/H

   C ______M/H

   M ______M/H
5. SUBSYSTEM ....______
6. MAINTENANCE DELAY TIME ....______hr
7. REASON FOR MAINTENANCE DELAY: ______________________________

8. REASON FOR CORRECTIVE MAINTENANCE: ______________________________

*MAINTENANCE: PW = Public Works personnel

C = Contractor personnel

M = Military personnel

FORM 4

ROUTINE MAINTENANCE

PAGE NO. ____

1. DATE/TIME MAINTENANCE STARTED ....______mo/day/yr ______hr/min
2. DATE/TIME MAINTENANCE COMPLETED ....______mo/day/yr ______hr/min
3. TOTAL TIME OF ROUTINE MAINTENANCE ....______hr/min
4 MAN-HOURS OF ROUTINE MAINTENANCE* ....PW ______M/H

   C ______M/H

   M ______M/H
5. SUBSYSTEM ....______
6. MAINTENANCE DELAY TIME ....______hr
7. REASON FOR MAINTENANCE DELAY: ______________________________

____

____

____

____

8. DESCRIBE ROUTINE MAINTENANCE PERFORMED: ______________________

____

____

____

____

*MAINTENANCE: PW = Public Works personnel

C = Contractor personnel

M = Military personnel

FORM 5

WEEKLY DATA TOTALS

WEEK ENDING ________ PAGE NO. ____

A. HRI SYSTEM:

				PW	C	M
1.	OPERATING TIME	_____hr	MAN-HOURS	____	____	____
2.	ROUTINE MAINTENANCE	_____hr	MAN-HOURS	____	____	____
3.	CORRECTIVE MAINTENANCE	_____hr	MAN-HOURS	____	____	____
4.	OPERATIONAL IDLE TIME	_____hr				
5.	NONOPERATIONAL IDLE TIME ...	_____hr				
6.	DOWNTIME	_____hr				
7.	SOLID WASTE NOT ACCEPTED	_____lb				
8.	SOLID WASTE RECEIVED	_____lb				
9.	SOLID WASTE REJECTED	_____lb				
10.	WET ASH REMOVED	_____lb				
11.	FLY ASH REMOVED	_____lb				
12.	STEAM FLOW	_____lb				
13.	MAKE-UP WATER	_____gal				
14.	PRIMARY BURNER FUEL	_____gal	_____gal			
15.	SECONDARY BURNER FUEL	_____gal	_____gal			
16.	LOADER FUEL	_____gal	_____gal			
17.	CONSUMABLES ....WATER	_____gal	SO_3 _____	other_____		
	ELECTRICITY	_____kw	PO_4 _____			
	REPLACEMENT PARTS	_____$	SALT _____			

B. SUBSYSTEM:

		OPERATING TIME	ROUTINE MAIN.	CORRECTIVE MAIN.
1.	PROCESSING	_____hr	_____hr	_____hr
2.	INCINERATION	_____hr	_____hr	_____hr
3.	ASH REMOVAL	_____hr	_____hr	_____hr
4.	STEAM GENERATION	_____hr	_____hr	_____hr

APPENDIX C

MAINTENANCE EVENT SUMMARY TABLE

AND INSTRUCTIONS

A. MAINTENANCE EVENT SUMMARY TABLE

The Maintenance Event Summary table is used to document data related to HRI system malfunctions and failures.

1. Examine all reports of HRI system maintenance events as documented on the corrective maintenance FORM 3. Using the table format, arrange all maintenance events in chronological order and assign event numbers accordingly.

2. Refer to line 5 of FORM 3. Identify and record the subsystem location in the designated column of the table using the following categorization:

   P - Processing

   I - Incineration

   R - Ash Removal

   S - Steam Generation

3. Refer to line 8 of FORM 3. Identify and record the malfunctioning or failed part in he designated column of the table.

4. Refer to line 3 of FORM 3. Record the maintenance event repair time in the designated column of the table.

5. Refer to line 8 of FORM 3. Record a brief discussion of the circumstances surrounding the maintenance event.

6. Classify the maintenance event as either a maintenance action or a failure using the following criteria:

   a. Failure - a maintenance event that involves a severe deterioration, break, or wear-out of a component part that degrades equipment operation below specified levels and which requires repair or replacement of the component part.

   b. Maintenance action - a maintenance event that requires the readjustment or unjamming of a component part to restore equipment to specified levels of operation.

MAINTENANCE EVENT SUMMARY TABLE

EVENT NO	DATE	CLASSIFICATION	SUBSYSTEM	COMPONENT	REPAIR TIME	DISCUSSION

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